Progress of the SPIRAL2 Project

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Abstract

This paper presents the progress of the SPIRAL2 project, the R&D and tests of the key components should be reviewed together with the main challenges for the beam production.

INTRODUCTION

The SPIRAL2 facility will extend the possibilities offered at GANIL to heavier radioactive beams, with much higher intensities [1]: it will provide intense beams of neutron-rich exotic nuclei (10^6–10^{11}pps in the mass range 60 to 140), created by the ISOL production method. The extracted exotic beam will be used either in a new low energy experimental area called DESIR, or accelerated by the existing SPIRAL 1 cyclotron (CIME).

The intense primary stable beams (deuterons, protons, light and heavy ions) will also be used at various energies for nuclear physics (e.g. study of superheavy elements, neutron deficient nuclei…), as well as for neutron-based research and multi-disciplinary research, all these experiments taking place in a new area (AEL, consisting of S3 and NFS).

After a detailed design study phase (2003-2004), the SPIRAL2 radioactive ion beam facility at GANIL was officially approved in May 2005. The project group for the construction was launched in July 2005, with the participation of French laboratories (CEA, CNRS) and international partners.

During year 2008, the decision has been taken to build the SPIRAL2 machine in two phases:

- first phase including the driver accelerator and its associated new experimental areas (S3 and NFS caves),
- second phase including the RIB production part, with the low energy RIB experimental hall called DESIR, and the connection to the GANIL existing facility for post-acceleration by the existing CIME cyclotron.

The SPIRAL2 facility is now in its construction phase, with the objective of obtaining the first beams for physics by the end of 2013 with the first phase [2].

SPIRAL2 DRIVER ACCELERATOR AND AEL EXPERIMENTAL AREA

Beams to be Accelerated

In order to fulfil the physics requirements, the SPIRAL2 driver accelerator must be able to accelerate high-intensity beams of protons, deuterons, ions with q/$A>1/3$, and optionally ions with $q/A>1/6$. As indicated in table 1, a maximum beam power of 200kW is required for deuterons in CW mode.

Table 1: Beam Specifications

beam	P+	D+	ions	ions
Q/A	1	1/2	1/3	1/6
Max. I (mA)	5	5	1	1
Min. output W (Mev/A)	2	2	2	2
Max output W (Mev/A)	33	20	14.5	8
CW Max. beam power (KW)	265	200	44	48

Injector-1

The Injector-1, dedicated to protons, deuterons and q/A=1/3 ions, is mainly composed of two ECR ion sources with their associated LEBT lines, a warm RFQ and the MEBT line connected to the LINAC (see Fig. 1)

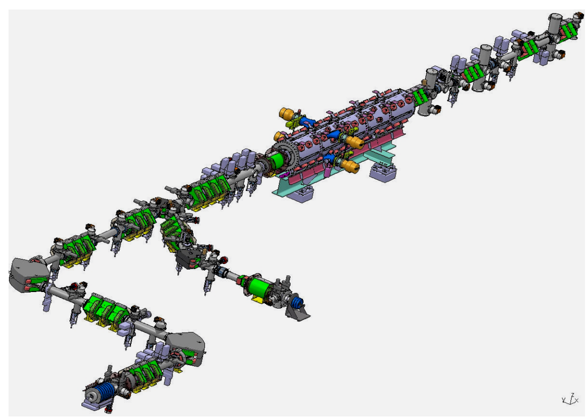

Figure 1: View of injector-1 (LEBT, RFQ and MEBT).

The 2.45GHz ECR source for deuterons and proton is a “simplified” SILHI-like source (100mA CW, 95kV), initially developed by the CEA/IRFU laboratory for the IPHI project. The ECR source for SPIRAL2 is now constructed and fully tested. It has demonstrated its capability to produce a very stable 6.7mA D^+ CW beam with an rms normalised emittance less than 0.1π.mm.mrad. It also produces protons (5mA) and H_2^+, with a voltage of 20kV for protons.

All the equipments of the LEBT lines, dedicated to deuterons, are built. The deuteron LEBT2 and the common LEBTC lines are installed at CEA/Saclay (Fig. 2).

Figure 2: View of ECR deuteron source and its associated LEBT lines mounted at CEA/Saclay.

The technical commissioning of the LEBT2 and LEBTC has been successfully performed (vacuum, automats, CC Epics, faraday cup, slits, chopper….). Beam tests are being performed and an emittance lower than 0.2 π.mm.mrad has been measured in D+ beam close to the RFQ injection point[3].

The objective for SPIRAL2 is also to produce a large diversity of heavy ions with intensities up to 1mA: noble gases like Ar^{12+}. Metallic ions like Cr, Ni and Ca, are first required. The final source, which will be installed on SPIRAL2, is not yet chosen.

The LEBT1 line are built and tested at LPSC laboratory with their PHOENIX-V2 ECR heavy ion source (Fig. 3).

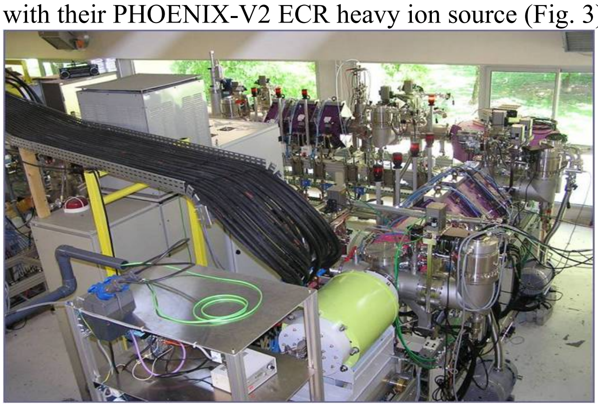

Figure 3: View of PHOENIX-V2 source and its associated LEBT1 line mounted at IN2P3-LPSC/Grenoble

The technical commissioning is completed and different beams have been produced to successfully qualify the LEBT1 line on the beam dynamics point of view. It help us also to develop and qualified at an early stage various important point like CC, power supplies etc....

Developed by the CEA/IRFU team, the RFQ [4] is a 4-vane, 5-meter long normal conducting copper cavity ensure adiabatic bunching (88Mhz) of the continuous beam, and acceleration at 0.75Mev/u (β=0.04). It is specially designed to give a transmission better than 99%. The construction of the RFQ has started. The 1-meter segment T5 is built but not yet assembled. The mechanical tests revealed non-conformities which has forced us to reconsider the tolerance objectives. The realization of segments T1 to T4 has started and they should be delivered before june 2012, just on line with the installation planning.

The MEBT line takes care of the beam transmission and matching between the RFQ exit and the LINAC entrance. Its function is also to allow future connection of the injector-2, and to operate a fast chopping of the beam in a single bunch mode, for various AEL experiments. This explains the length of this part (8m) and the necessity to use three rebunchers in order to match the beam longitudinally. All the magnets are manufactured and qualified. The first rebuncher has been successfully tested. The construction of the two others can start now. The calls for tender of the mechanics and the vacuum system of this MEBT line are ready to be launched. One exception is the challenging fast chopper and its associated 7.5kW beam stopper. The chopper chamber (INFN-LNS, FP7/SP2PP) [5] is still in a detailed design phase and the first prototype should be ready by november this year [6].

Injector-2

The optional Injector-2 will be dedicated to q/A=1/6 heavy ions connected to the LINAC via the MEBT line. This injector has been studied in detail in order to prepare enough space in the accelerator building for the future. Although the final energy of the q/A=1/6 ions will be half of the q/A=1/3 ions, there is much interest in having higher beam intensity for very heavy ions.

Linac

The LINAC accelerator itself is based on superconducting independently-phased resonators [7]. It is composed of 2 families of quarter-wave resonators (QWR) at 88MHz, developed respectively by the CEA/IRFU and the IN2P3/IPNO teams [8]: The first family is composed of 12 resonators with β_0=0.07 (1 cavity/cryomodule), and and the second family of 16 resonators at β_0=0.12 (2 cavities/cryomodule). The transverse focusing is ensured by means of warm quadrupole doublets located between each cryomodule. They are presently under magnetic measurement.

The maximum reference gradient in operation of the QWRs is $E_{acc}=V_{acc}/\beta\lambda$=6.5MV/m. All the β_0=0.07 cavities are built and their tests are going on. Concerning β_0=0.12 cavities, they are built and have all been tested in a vertical test-cryostat. They all reached the maximum reference gradient, with the reference Q_0.

The first β_0=0.07 cryomodule, is assembled and is under tests. We face pollution difficulties. Qualifying cryomodule, for β_0=0.12 cavities, met the specifications but we have dust pollution difficulties with production cryomodules. Analysis is going on. Both cryomodules are presented in Fig. 4.

Developed by IN2P3/LPSC, the RF power couplers have to provide up to 12kW CW power to each cavity [9].

All the couplers are received and are being commissionned.

Solid-state amplifiers will be used to power the linac cavity[10]. They are being manufactured and first units will be tested at the manufacturer site in september 2011.

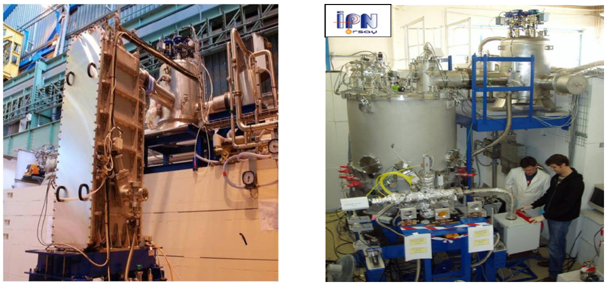

Figure 4: The SPIRAL2 superconducting cryomodules (left: β_0=0.07- 1cav, right: β_0=0.12- 2cav).

HEBT Lines and AEL Experimental Hall

The high energy beam transfer lines (HEBT) are divided into two main parts (Fig. 5):

- HEBT1: A straight beam line with a beam dump is needed for the beam commissioning and potential tuning and beam studies. The beam dump can handle a maximum beam power of 200kW. Depending on nuclear safety licensing requirements, mainly related to the material activation, the effective beam power will depend on ion species.

This line will also deliver a deuteron beam to the NFS cave for neutron experiments with a neutron time-of-flight facility

- HEBT2: This transfer line will transport light- and heavy- ion beams towards the RIB production area, located in a separate building (see next section).

This line will also deliver light and heavy ions beams to the S3 cave for high-intensity stable ions experiments with a high mass selectivity spectrometer.

All the detailed studies of these lines are completed. The magnets are under fabrication, the call for tender for vacuum systems is on the way to be launched and the call for tender for the mechanics is in preparation.

The HEBT lines will contain several rebunchers in order to keep the beam bunched, with a bunch length as small as possible at the target (<1ns). These rebunchers are not studied yet.

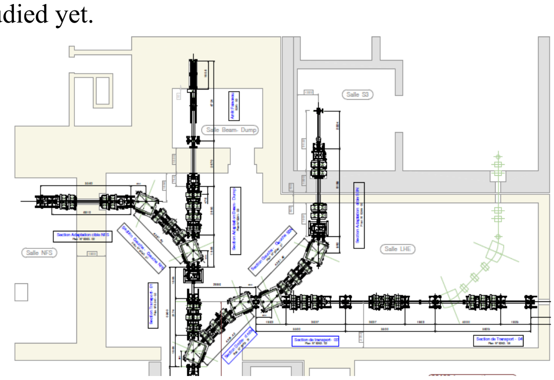

Figure 5: View of the HEBT lines.

BUILDINGS FOR ACCELERATOR AND AEL EXPERIMENTAL AREA

After writing a detailed specification of the buildings, the contest to choose the company in charge of studies of these buildings was launched in early 2008. The choice of the company was made in the fall of 2008 and therefore the studies of buildings started just afterwards.

The call for tenders for buildings work packages, was launched in april 2010 and contracts, with companies in charge of buildings WP, were signed in february 2011.

The first concrete pouring is expected in mid september of this year (Fig. 6).

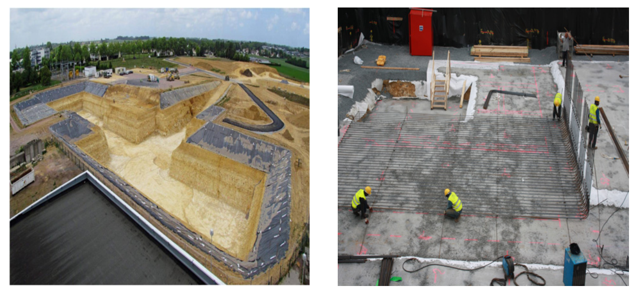

Figure 6: views of the construction site under way.

SPIRAL2 RADIOACTIVE BEAM AREA

The layout for the target ion-source (TIS) and the RIB transport lines in the production building is defined and is illustrated in Fig. 7.

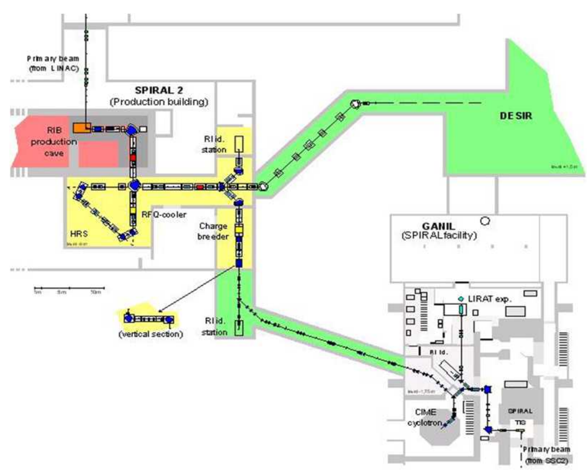

Figure 7: General layout for the RIB part.

TIS Production System

For the production of the RIBs at the future ISOL facility SPIRAL 2 different production methods are being foreseen. The primary beams (d, p or heavy ions) will impinge on different target materials and produce the RNBs. The targets are heated above 2000°C to decrease the diffusion time of the products that will then effuse toward an ion source for transformation to 1+ ions. In order to be able to reach so far unexplored regions of the chart of isotopes, the facility is designed for a production of 10^{14} fissions/sec. The neutron flux used to fission the UCx target is produced by a 200 kW deuteron beam impinging on a neutron converter consisting of a rotating graphite wheel. To increase the number of different exotic elements and isotopes produced, the UCx target can be replaced with other target materials for neutron induced reactions or without the neutron converter using transfer or fusion-evaporation reactions with the primary beams. Mainly four different 1+ ion sources are foreseen at the production station: laser ion source, surface ion source, ECR ion source and a Febiad type of ion source.

The developments, prototyping and tests of the different targets, ion sources and neutron converter are going on. For the startup of the installation a decreased intensity of the deuteron beam impinging on the graphite converter will be used. The first complete prototype of the 50kW size converter is under construction at LNL-INFN laboratory. Individual parts have already been tested [11]. The UCx target development, to find an optimum target for the production, is going on at the IPN Orsay laboratory. For the other targets to be used a study for thin targets is undertaken at CENBG in France.

A 2.45 GHz ECR ion source MonoBob has been developed at GANIL and has delivered ionization efficiencies up to 80% for the noble gases [12,13]. A Febiad ion source is being developed at IPN Orsay [14,15]. The laser ion source is consisting of a Ti Sa solid state laser installed at GANIL [16]. The first ions of Ga were produced on the off-line separator recently and a test program is foreseen to measure the efficiencies and ionization levels of different elements from the end of this year. A prototype of a surface ion source was tested in 2010 [17].

The detailed study of the TIS production module is completed (Fig. 8). The production module is a totally remote-operated system taking into account radiological environment, safety and contamination handling rules.
The construction of a prototype of the production module could begin in the fourth quarter of 2012.

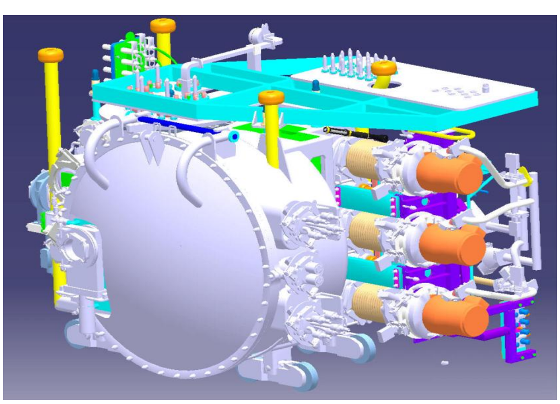

Figure 8: TIS production module.

Beam Transport Lines to DESIR Experimental Area and to Existing GANIL Areas

The radioactive beam transport lines from the production cave towards the experimental areas have been designed from the beam-optical viewpoint.
These lines are composed of the following subsystems:

- 1+ line, going from the ion sources towards an identification station (IBE1+), the low-energy experimental area DESIR or the charge booster,
- RFQ Cooler to decrease beam emittance,
- High Resolution Separator for mass separation,
- charge booster,
- two identification stations for 1+ and n+ RIBs,
- n+ line that transports the beam from the charge booster to CIME cyclotron.

The preliminary design of 1+ line is achieved. The integration studies in the buildings, taking into account the constraints of maintenance, are in progress. The mechanical design of the line is based on the use of independent modules that will be extracted with remotely operated tools from inaccessible places like the production caves.

A RFQ Cooler and a High Resolution Separator (HRS) will be installed in the production building. for the low energy RIB purification before its transport to DESIR experimental hall.
A prototype of the RFQ has been built and the tests with beam are in progress [18]. The nuclearization of its mechanical design, for maintenance operation in a zone where radioactivity and/or contamination will become important, is under studies.
Concerning the HRS, beam dynamics is fixed and now the feasibility study of the magnet is underway. The goal is to launch the manufacturing in 2012 in order to install and test the HRS in CENBG [19].

The charge booster, needed to inject the RIB into the CIME cyclotron, is a Phoenix type developed by the LPSC laboratory [20]. Charge breeding has been tested on the LPSC test bench with the MONOBOB ECR 1+ source. The nuclearization of its mechanical design is well advanced.

Two identification stations will be installed in the production building, one for 1+ RIB and the other for n+ RIB. The detailed study is over.

The preliminary design of the n+ line, that transports the beam from the charge booster to CIME cyclotron, is complete. The integration and the maintenance of these lines in the buildings have been taken into account. Their detailed study has still to be started.

BUILDINGS FOR PRODUCTION AND DESIR EXPERIMENTAL AREA

After writing the specifications of the buildings, the contest to choose the company in charge of studies of these buildings was launched in early 2008. The choice of the company was done mid of 2010.

The studies of buildings have started. The preliminary design is complete. The detailed studies will start and must end in march of next year. The construction of the buildings should start in early 2014.

CONCLUSION

The major parts of the injector and the superconducting SPIRAL2 accelerator are now constructed and under tests. The HEBT lines are about to be launched in manufacturing. After installation and beam tests at LPSC Grenoble and Saclay, the sources and their associated LEBT lines will be transported and installed at GANIL, in parallel with the LINAC and the HEBT lines. The beam tests should start by mid-2013.

The preliminary design study phase of the radioactive beam area is now achieved. Integration and maintenance aspects, in the production building, have been treated. The final detailed studies should be completed by the end of the year 2012.

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